

Processes, Threads, and Concurrency

CSE 220: Systems Programming

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Logical Control Flows

Computer Systems: A Programmer's Perspective defines a **logical control flow** as:

[A] series of program counter values that [correspond] exclusively to instructions contained in [a program's] executable object file or in shared objects linked to [it] dynamically at run time.

The system provides each program with the illusion that its logical control flow **runs on a dedicated computer**.

Concurrency

Concurrency is when more than one **logical control flow** is present in the system at the same time.

Concurrent flows are logical control flows whose execution overlap in time.

Concurrent flows can be present **even with only one processor**.

Multiple flows can coexist on one processor via **multitasking**.

Multitasking **time slices** between multiple logical control flows.

- Each flow runs for a brief period of time, then is interrupted
- A **context switch** changes control to another flow
- The new flow runs for a brief period of time (*repeat*)

The Process

Our fundamental logical control flow abstraction is the **process**.

A process encapsulates:

- A set of instructions
- The memory they use
- The system resources they access
- ...

All interactions with other processes are **through the OS**.

This is **due to the dedicated computer model**.

Threads

Threads provide a **conceptually similar** abstraction to processes.

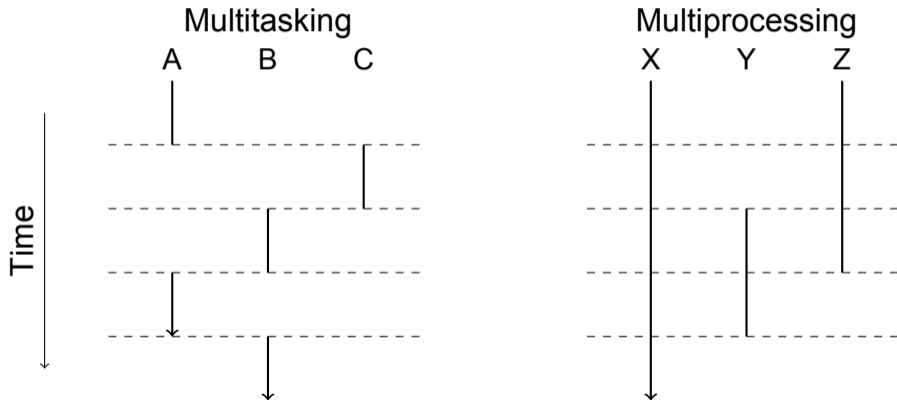
Threads also represent a **logical control flow**.

However:

- **One process** may have **multiple threads**
- Two threads within one process **are much less isolated** than two processes, or threads in different processes

In particular, **threads within a process share a memory map**.

Multitasking and Multiprocessing



Multitasking

Concurrent flows in a **multitasking** environment do not execute simultaneously.

However, **from the point of view of any given flow**, other flows are making progress while it executes.

Consider:

- Process A is executing at PC location L
- A **context switch** occurs, removing A from the CPU and switching to Process B
- Process B does something
- A context switch occurs, switching to Process A at location L

Process A will observe progress in Process B before and after L.

Multiprocessing

Concurrent flows in a **multiprocessing** environment may execute simultaneously.

Even with multiprocessing, multitasking may **also** be used.

This is **typical for modern systems**.

The **operating system** provides the illusion of a dedicated machine **even to processes running simultaneously**.

Concurrency and Separation

Concurrent flows may be **related** or **unrelated** in:

- Design
- Implementation
- Memory space
- Resource requirements
- Timing requirements
- ...

When concurrent flows are **completely unrelated**, the **dedicated computer** abstraction provided by modern systems is both mostly complete and very appropriate.

When they are **more related**, it gets more complicated.

Motivation for Concurrency

There are many reasons to use concurrent flows:

- Making computational progress while **blocked** on a slow device
- Achieving **rapid response** to a particular condition (e.g., human input, external event)
- Utilizing **multiple physical processors**
- ...

In addition, **simply taking advantage of the dedicated computer model** to simplify design and implementation.

Processes

We have already seen [process-level concurrency](#).

(Consider the chat client and server!)

Multiple processes may:

- Proceed independently on [unrelated tasks](#)
- Proceed independently on [related tasks](#)
- [Cooperate](#) on tasks

Designing for Multiple Processes

A multi-process design can be **robust and reliable**.

The **isolation** in **memory and resources** provided by the system protects processes from certain faults in their neighbors.

Communication and cooperation can be expensive, though:

- Separate memory spaces protect, but also divide
- Many **inter-process communication** (IPC) mechanisms require **interaction with the OS**, which is slow

Most modern web browsers use multiple processes for this reason!

Threads

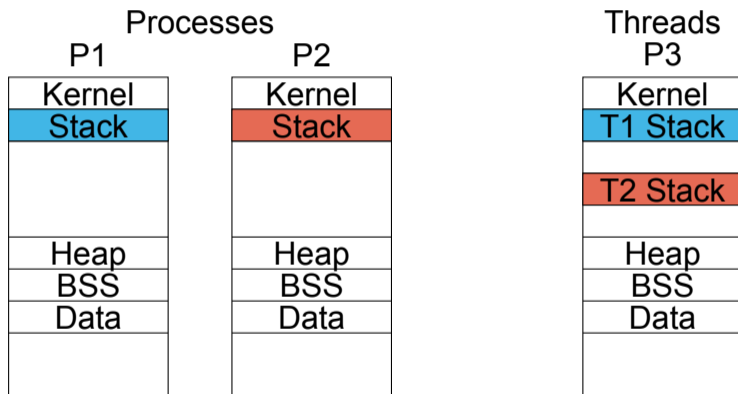
Thread are **like processes that share almost everything**.

They:

- Share memory
- Share system resources (such as open files)
- Run the same executable code
- ...

Switching between threads is **often less expensive** than processes in a multitasking system.

Threads vs. Processes



Threading Advantages

Threads are **much cheaper** than processes:

- They share memory maps
- They share permissions and operating system resources
- Context switches between two threads in the same process are much less involved than between processes

Inter-thread communication is **trivial**, due to shared memory.

Threading Disadvantages

Concurrent access to shared resources is **very tricky**.

Many established APIs are not **thread-safe**.

(Over the next few lectures, think about a thread-safe `malloc()`!¹)

Breaking down the **dedicated computer model** makes reasoning about process behavior harder.

¹But you are *not* required to implement one!

Threading Use Cases

Threading is often appropriate for tasks which require:

- Very **rapid change of control** between parallel tasks
- Lots of **large, shared data** structures
- **Blocking operations** that do not inhibit other progress
- **More rapid computation** than can be performed on a single CPU

Multiple processes may also solve some of these problems.

The costs of threading must be weighed against its advantages on a **case-by-case basis**.

Summary

- Logical control flows are **execution steps through programs**.
- Concurrency is **multiple logical control flows at one time**.
- **Multiprocessing versus Multitasking**
- **Processes versus Threads**

Next Time ...

- Races and Synchronization

References I

Required Readings

- [1] Remzi H. Arpaci-Dusseau and Andrea C. Arpaci-Dusseau. *Operating Systems: Three Easy Pieces*. Chapter 26: Intro, 26.1. Arpaci-Dusseau Books. URL: <https://pages.cs.wisc.edu/~remzi/OSTEP/>.

Optional Readings

- [2] Randal E. Bryant and David R. O'Hallaron. *Computer Science: A Programmer's Perspective*. Third Edition. Chapter 8: 8.2; Chapter 12: Intro, 12.1, 12.3. Pearson, 2016.

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